An improved data acquisition system for Detection and search of :

Supernova Neutrinos in IceCube

The IceCube Collaboration
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Abstract

The IceCube Neutrino Observatory was designed to detect neutrinos at energies greater than 100 GeV. Due to subfreezing temperatures, the photomultipliers' dark noise rates are particularly low. This enables IceCube to search for neutrinos from galactic supernovae by measuring an increase in the overall hit number, deduced from scalers, in the detector coming from the Cerenkov light of interactions of MeV neutrinos in the ice.
A new feature to the standard DAQ, called HitSpooling, is running in IceCube since 2013. By buffering the untriggered hit information of the photomultipliers we have access to the full raw data stream of the detector in case of a supernova. In combination with the standard scaler data, the HitSpooling feature leads to a better understanding of background processes coming from atmospheric muons and instrumental noise.
Furthermore, the status of the galactic supernova search as well as systematic and detector stability studies are presented.

Data Streams

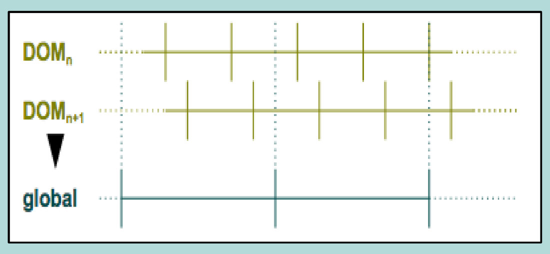
Hit Data

Artistic drawing of IceCubes Digital Optical Modules (DOM)

- ***Basis for IceCube's standard analysis channels***
- ***Hit** := PMTs anode exceeds discriminator threshold of 0.25 single-photo-electrons*
- Hit holds a timestamp, a 3-bin peak- or full sample of the waveform, depending on trigger conditions.
- DAQ elements involved in capturing, aggregating and transferring the data from a hit:
  - ***DOM***: digitization of the waveform in a time-interval of 6.4 µs
  - ***DOMHub***: an industrial computer communicating with all DOMs of 1 string. Located in surface laboratory
  - ***StringHub*** : software element on DOMHub. Collects *hits.* Converts DOM hits in physics-ready hits that are suitable for higher level software elements like triggers and event-builders

Scaler Data

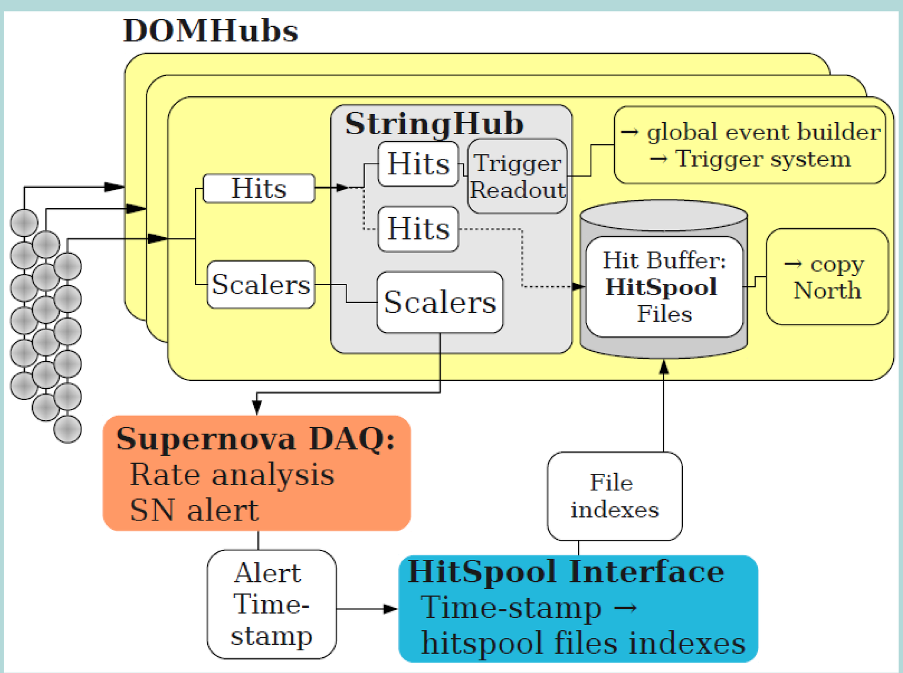
- ***Basis for IceCube's Supernova data acquisition system and supernova analysis channel***
- Independent of the hits data coincidence conditions
- Firmware integrated scaler adds asynchronously all PMT pulses in intervals and assigns them a timestamp
- Supernova DAQ [A&A11] collects scaler data from individual DOMs and rebins to global 2 ms intervals
- Supernova DAQ calculates individual noise rates
- Data distribution approximated by Gaussian distribution:
  ➤ Expectation values and corresponding standard deviations for noise values
- Most likely *collective rate deviation,* $\Delta\mu$, and its uncertainty, $\sigma_{\Delta\mu}$ give the *significance* $\xi = \Delta\mu / \sigma_{\Delta\mu}$
- Supernova DAQ issues an alert to SNEWS [NJP04] for standard deviation $\sigma > 5.2$
  ➤ ***SN candidate trigger*** ($f \approx 1$ every 2 weeks)



Scaler rates from individual DOMs in 1.6384 ms bins are combined to a global 2 ms binning

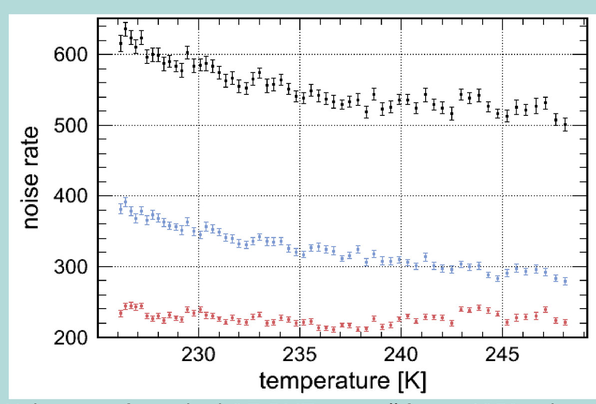
HitSpool Data

- Additional to hits in memory: Hits data buffered to disk in DOMHub (dashed line in diagram)
- 2 MB of data per second per string
- Hits buffered in a cycle in files of variable duration
- Buffer length up to 16 hours
- HitSpooling independent of other DAQ elements
- Data transfer to central storage in case of an SN candidate trigger is handled by the HitSpool Interface services [ICRC13A]

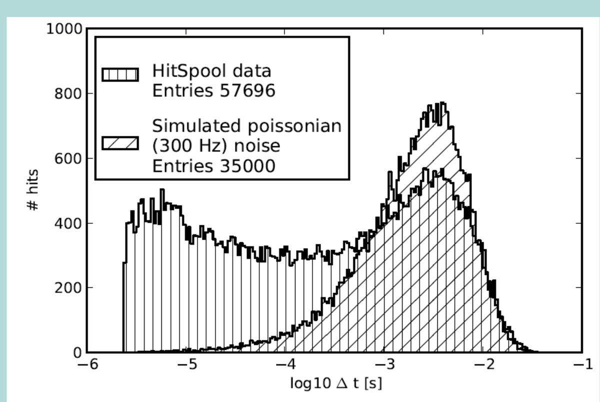


Background

- Supernova analysis algorithm based on subtle changes in the background rate
- Single DOM noise averages at 540 Hz
- Considered background for supernova search:
  - Uncorrelated Poissonian contributions:
    - radioactivity, thermal noise, field emission
    - Atmospheric muons
  - Correlated noise:
    - Cherenkov radiation and/or scintillation
- Suppression of correlated noise:
  - Artificial dead-time of 250 µs applied to every hit in scaler data
  - Remaining noise rate 285 ± 26 Hz [NIMA10]
- Triggered atmospheric muons
  - Muon trigger rate in IceCube per DOM: 16 Hz
  - Removing hits associated with muon trigger improves the significance distribution
  - Further improvable by using HitSpool data (see next column)



Noise rate of standard QE-PMTs on well frozen IC59 strings. Average rates per depth in total (black) and for correlated noise (blue) and Poissonian (red) separately.



Logarithmic time distribution of successive hits in a single DOM. Contributions by uncorrelated noise hits from radioactive decays are simulated with 300 Hz

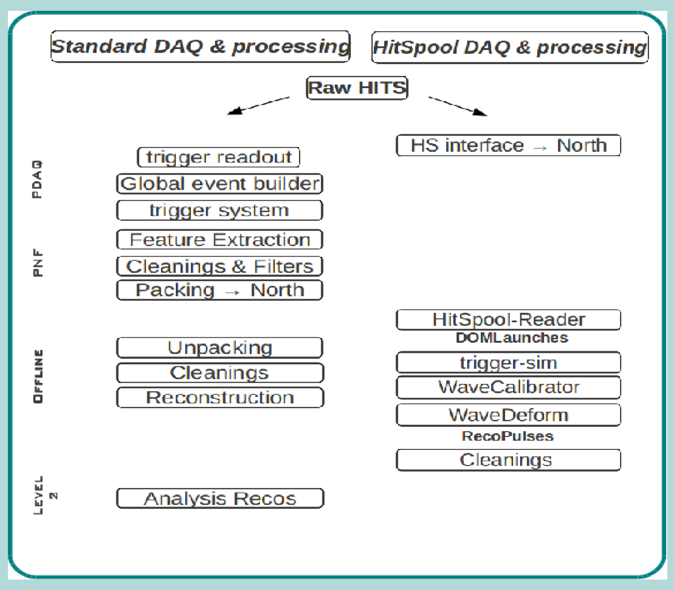
Introduction

- Neutrino interaction in ice: Dominant interaction in ice for supernova neutrinos with energy O(10 MeV) is the inverse beta process: $\bar{\nu}_e + p \longrightarrow e^+ + n$
- Positron tracks of about 0.56 x E_ν [cm/MeV]
- Monte Carlo: For 10^7 neutrinos interactions in ice from a supernova at 10 kpc distance we expect to detect up to 3.6 million neutrino induced PMT hits.
- Detection principle: monitoring the count rates of individual DOMs in ms time bins.
- Scaler data stream is decoupled from the hit data stream that holds more detailed information, but is only saved for events that trigger and may not be available in the case of a supernova.

HitSpool Processing

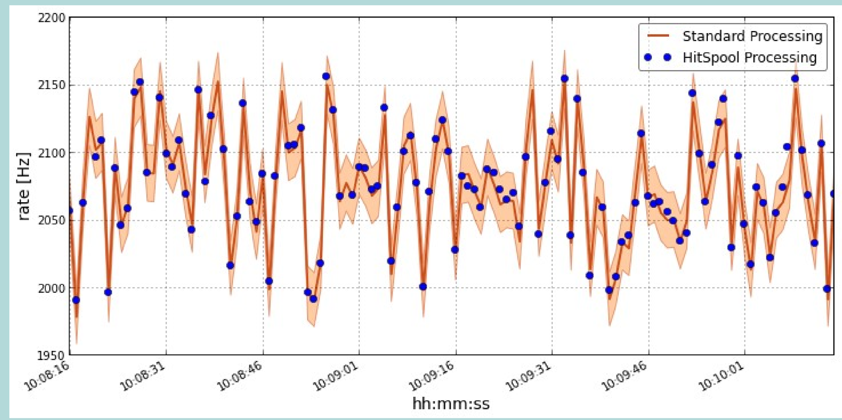
Processing Chain

- HitSpool data is processed offline in the North
- Hybrid processing system:
  - tools from simulation production and experimental data processing at the same time
- > 20 data sets of 105 seconds collected
- Processing optimised for keeping background and identify even sub-threshold atmospheric muons (see next column)



Verification

- Comparing processed HitSpooling data with standard
  - Triggers (from hit data stream): e.g. *Simple Majority Trigger* [VLVnT13] is correctly reproduced offline
  - Significances (from scaler data stream): Recalculation, based on hitspool data, fits to Supernova DAQ result



Trigger rate comparison. Exemplary shown is IceCube's Simple Majority Trigger (solid line). The trigger rate obtain from hitspooling data in offline processing (blue dots) is within the accepted one percent deviation band (shaded area).

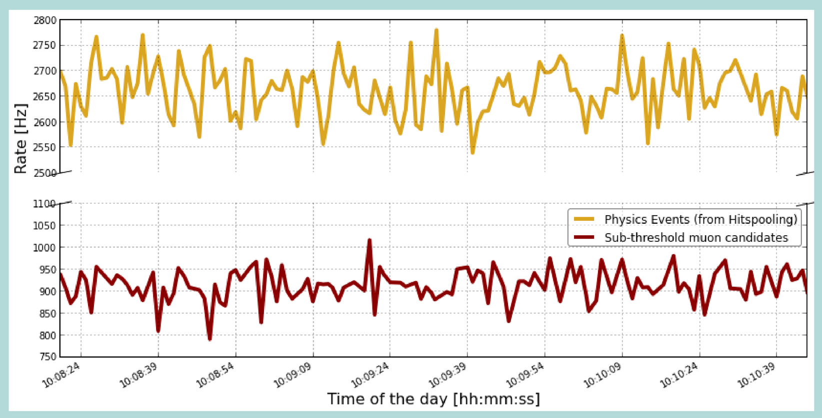
Sub-trigger Muons

Motivation

- Subtraction of triggered atmospheric muons already improves significance distribution (see box below)
- For best separation between noise & signal:
  - Identify and subtract hits associated to atmospheric muons that did not trigger
  ➤ Cleaned data set with narrowed significance distribution and reduced non-Gaussian tails

Tools

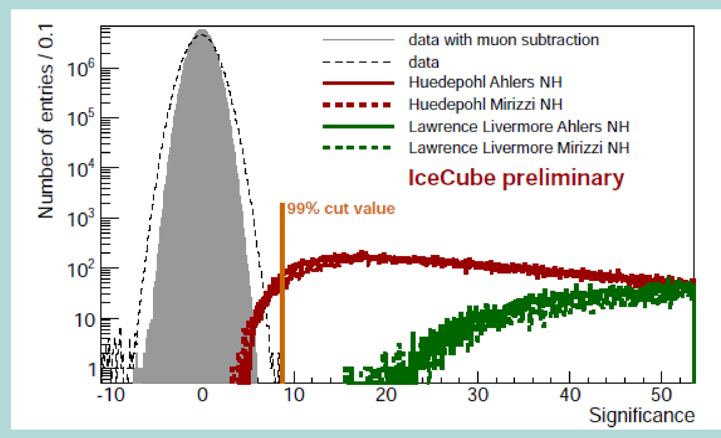
- Hit cluster identification
- Inverted hit cleaning
- NoiseEngine [Lars13]:
  - Identification of tracks by hit pair angular multiplicity
  - Estimation of track's consistency with noise or muon
  ➤ ***Sub-threshold muon candidates***

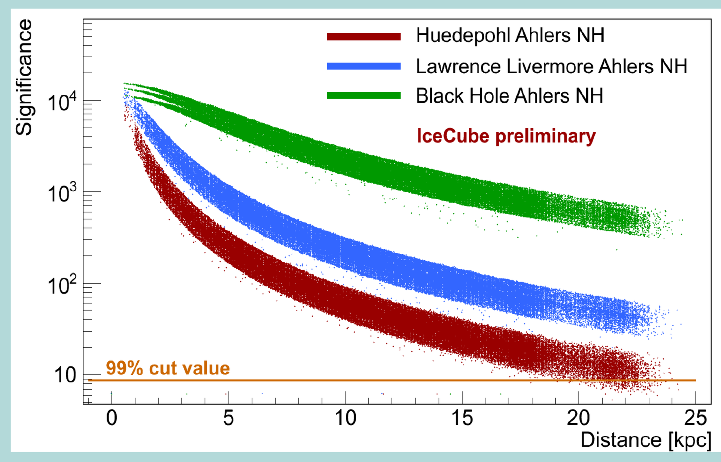


Physics event rate (i.e. global merged trigger rate) in hitspool data (yellow) compared to sub-threshod muon candidate rate (red).

Supernova Search

- Measured significance distributions without (black line) and with (shaded grey) subtraction of atmospheric muons for data taken from April 2008 to May 2011 (significances ξ above 6 are kept blind). The distributions hardly overlap with the significances expected for the three supernova models studied assuming two progenitor radial distribution models for our Milky Way (solid lines: [JCAP06] , dashed lines: [PRD09])
- Simulated significance distribution for the detection of a supernova as function of distance for the Hüdepohl [PRL10], Lawrence-Livermore [AP88] and Black Hole [AJ07] models





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